

Improving Stability of Low-Volume Forest Roads Using a Lignin-Based Emulsion

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ABSTRACT – Unitol DKG, a lignin-based emulsion used to stabilize road surfaces was tested on a low-volume forest road near Chapman, Alabama. Two replicates of three treatments were applied during October 1999 that included a 3:1 dilution of Unitol DKG, a 6:1 dilution, and pack & grade with no chemical. Also, two control sections were located at each end of the test area. California Bearing Ratio (CBR) and moisture content were measured the following November and March. In addition, soils treated with three different dilutions of the product were subjected to Unconfined Compression (UC) and CBR tests in a lab. Adding the Unitol appeared to bind the soil together. Strength appeared to develop with time in treated road sections. The field CBR's consistently increased from November to March for the chemically stabilized and pack & grade sections. The 3:1 dilution had the best strength performance in the field tests, while the 6:1 dilution was not much different from the control sections. There was not a significant difference in the performance of the various dilutions in the UC tests. The UC tests showed increased plasticity at the lower dilutions. The saturated lab CBR tests showed that the 3:1 dilution retained its cohesiveness under wetted conditions. The lab CBR tests showed higher strength in the weaker dilutions than in the 3:1.

INTRODUCTION

Forest roads are designed to provide access. They must safely carry heavy traffic, provide access during a range of weather conditions, provide service without excessive maintenance, and minimize impacts to water quality. The fundamental problem that forest road designers must address is developing adequate strength in the sub-grade.

Given the economic constraints, the most commonly applied road treatment is periodic addition of surfacing aggregate "as needed." In areas with good sources of rock, aggregate may be relatively inexpensive and readily available. Many regions, however, may not have access to good aggregate and rocking forest roads becomes an expensive option.

An alternative to rocking forest roads is to improve the strength characteristics of the native materials for road construction with the addition of chemical stabilizers. Many materials have been used to increase soil strength, including fly ash, ionic chemicals, lime, and lignin-based products. The performance of these additives is highly variable depending on soil type, climate, and application method.

Unitol DKG¹, a lignin-based emulsion that is derived from a by-product of the tall oil extraction process, may be a viable alternative for enhancing road strength. The by-product is water insoluble and additives are necessary to suspend the product in a water emulsion.

This product was applied at two different dilution rates on two 0.5-mile test sections of a low-volume forest road to

improve strength. Application of the product on the test section was performed during October 1999 near Chapman, Butler County, Alabama. The project was a cooperative effort among International Paper Company, Woodland Enterprises, Arizona Chemical, and the Southern Research Station, Auburn, Alabama. Rather than spraying the product onto the road surface and mixing with a grader, a new approach was used where a soil stabilizer machine thoroughly mixed the product with the upper 8-inches of road surface. This approach offers the potential for better performance of the road and a greater increase in strength.

PROJECT DESCRIPTION

Test Area

The study was installed on two 0.5-mile sections of a forest road in Butler County, Alabama. Butler County is located in south-central Alabama on the Coastal Plain. The average daily temperature for the county is 65.1°F. Yearly precipitation averages 56.2 inches. Monthly rainfall amounts during the study period are displayed in Figure 1.

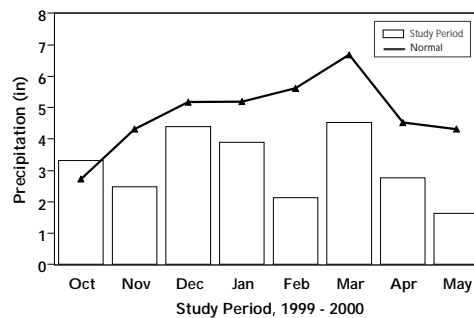


Figure 1. Rainfall amounts for area during study period.

¹ The use of trade names is for the convenience of the reader and does not imply endorsement by the USDA Forest Service.

According to the County's soil survey (Soil Survey of Butler County, Alabama, 1993) one test section was located predominately on a Lynchburg soil series and the other on a Luverne (LuB and LuC) soil series. These series had an AASHTO classification of A-2-7 and A-2-4, respectively. The Luverne series was located in areas with slopes ranging from 1 to 8 percent. The Lynchburg soil series was located in areas with 0 to 2 percent slopes. A soil classification summary is shown in Table 1. Procedures from ASTM D 2487-90 and ASTM D 4318-84 were used for soil classification determination.

Table 1. Unified Soil Classification

Soil Type	Liquid Limit	Plastic Limit	Plasticity Index	Group Symbol	Group Class
Lynchburg	27	20	7	SC-SM	A-2-4
Luverne	54	34	20	SM	A-2-7
Sandy loam ¹	58	36	23	SM	A-2-7
Loamy sand ¹	17	NP	17	SC	A-2-4

¹Lab soil

Treatments and Method of Application

Two replicates of three treatments were installed on two 0.5-mile test sections. One test section was located on flat terrain (Lynchburg) while the other test section contained slopes that ranged from 1 to 8 percent (Luverne). Treatments that were applied included: (1) a 3:1 dilution of water and Unitol, (2) a 6:1 dilution of water and Unitol, and (3) pack & grade with no chemical. Two control sections were located at each end of the first test section. Each treatment replication was installed in a 500-ft test block.

For treatment installation a Caterpillar SS-250 machine was used to till the road surface and apply the chemical. The chemical was transferred through a hose from a tank truck to spray nozzles located near the rear of the tilling drum of the SS-250. After tilling and spraying, the road was graded with a John Deere 770B and then packed with a smooth drum roller. The chemical was applied at different dilution rates, but a constant application rate of 1.125 gal/yd².

METHODS

Field California Bearing Ratio (CBR)

CBR is a widely accepted value for expressing soil strength and is defined as the ratio of the stress (psi) at 0.1 inches of penetration to a standard stress of 1000 psi, multiplied by 100. To determine CBR values of treated sections a Dynamic Cone Penetrometer (DCP) was used. The DCP

utilizes a cone penetrometer and a 20 lb drop hammer. The hammer is dropped a distance of 22.6 inches, which drives the cone into the soil and the penetration rate measured in mm/blow is recorded. DCP data were converted to CBR values using the formula in Bolander et al. 1995.

For each 500-ft test block, DCP readings were taken at three locations 125-ft apart to a depth of 18-inches. Test points were located in the center of the road and were collected during November 1999 and March 2000.

Field Bulk Density and Moisture Content

To assess bulk density and moisture content of the road surface, two samples were collected within each test block at the time the DCP readings were taken. A soil hammer with 2-inch diameter aluminum rings was used to extract samples from the surface layer at a depth of 2-4-inches.

Moisture content of the sub-grade was determined from samples taken with a Laurd's stick. The Laurd's stick was inserted into the hole left by the bulk density sample. This produced a core sample from a depth of 5-inches and below. The depth of penetration varied from point to point due to the hardness of the sub-grade.

Laboratory Unconfined Compression and CBR Tests

To assess the effect of soil type, chemical dilution, and moisture content on strength properties with the chemical treatment, loamy sand and sandy loam soils were collected from field locations in Lee County, Alabama. These samples were taken to the Soils Lab at the Civil Engineering Department at Auburn University for laboratory CBR and Unconfined Compression Tests.

Proctor tests were performed on both soils to determine optimum moisture content. Optimum moisture is the level of saturation a soil requires for maximum compaction potential. For the sandy loam soil, optimum moisture content was achieved at about 19 percent. The tests performed at optimum were intended to determine the best possible performance of the product.

RESULTS

Field California Bearing Ratio (CBR)

There was a noticeable difference in surface and sub-grade strength within treatments as reflected in the CBR values due to treatment and soil type.

CBR values were calculated for the upper 8-inches of road and for the sub-grade below. The measurements were taken in November and repeated in March (Table 2). The average CBR for the sub-grade on the Lynchburg was 22.7 while for

the Luverne it was 9.2. These sub-grade CBR values did not change from November to March. CBR values for the surface sections, however, increased over the 5-month period with the exception of the Control sections.

Table 2. Mean CBR for 0 – 8 inches.

Treatment	Soil Type	November	March
3:1	Lynchburg	27.6	47.5
	Luverne	13.2	20.5
6:1	Lynchburg	25.3	37.4
	Luverne	6.8	13.0
Pack & Grade	Lynchburg	7.4	21.0
	Luverne	5.9	10.7
Control	Lynchburg	17.0	16.3

Laboratory Unconfined Compression and CBR Tests

The laboratory tests of UC and CBR were conducted on representative soil samples rather than actual road material. The lab tests showed the more highly concentrated dilutions of chemical additive increased plasticity, but decreased ultimate strength compared to the control sandy loam (Table 3). UC tests could not be performed on the loamy sand due to insufficient cohesiveness.

Table 3. Mean stress and deformation of sandy loam soil.

Treatment	Mean Stress (psi)	Mean Deformation (inches)
Control	29.62	0.14
3:1	22.98	0.18
5:1	23.17	0.18
7:1	25.43	0.14

Two types of CBR test were run—unsoaked and soaked. The unsoaked tests were compacted at optimum moisture content and tested. The soaked samples were similarly compacted, but then subjected to a 96-hour soak prior to testing. Each dilution was replicated three times. For the sandy loam soil, the 3:1 dilution retained its strength even in saturated conditions. The control and 7:1 dilution had the highest CBR under unsoaked conditions but showed significant reductions in strength with saturation (Table 4). For the loamy sand, the control had the highest CBR for unsoaked and soaked conditions than all other treatments, although it had the largest percent decrease in strength. From the lab tests the 5:1 dilution appeared to perform well. It had the highest CBR value after soaking for the sandy loam soil and about the same CBR value as the 3:1 dilution for the loamy sand with the largest percent increase in strength. However, it appears that adding Unitol to a sandy soils (loamy sands and sands) might not be beneficial since the lab loamy sand with no chemical had the highest CBR value under unsoaked and soaked conditions.

Table 4. Mean CBR values for lab soils.

Treatment	Sandy loam %			Loamy sand %		
	US ¹	S ²	Change	US	S	Change
Control	11.3	4.9	-57	13.9	9.2	-34
3:1	9.4	9.4	0	6.6	7.0	+6
5:1	16.7	10.0	-40	6.1	6.9	+13
7:1	17.5	7.5	-57	5.7	6.0	+5

¹Unsoaked; ²Soaked

Bulk Density and Moisture Content

The soil cores collected in the initial post-construction sampling were analyzed for bulk density and moisture content. The results summarized in Table 5 show that the moisture content of the upper layer of the roadway was generally near the Proctor optimum moisture content (Lynchburg ~13%, Luverne ~22%). The Lynchburg soils were fairly uniform in moisture content. The Luverne soils, however, were significantly wetter in the sub-grade in all cases but one. In addition, the Luverne soils showed a consistent drying trend in the chemically treated sections.

Post-treatment soil sampling found that the mean bulk density for the Lynchburg test sections was 1.76 g/cm³ (17.2 kN/m³). For the Luverne test sections, mean bulk density was 1.58 g/cm³ (15.5 kN/m³). These values fall closely on the Proctor curves illustrated in Figure 2, suggesting that the installation achieved maximum compaction.

Table 5. Bulk density and moisture content summary.

Soil Type	Treatment	Road Layer	% MC		Bulk Density ¹	
			Nov	Mar	Nov	Mar
LyA ²	3:1	surface	13.02	11.47	1.78	1.70
		sub-grade	11.28	11.01	-	-
LyA	6:1	surface	12.00	10.35	1.78	1.65
		sub-grade	11.41	12.36	-	-
LyA	PG ³	surface	18.84	15.77	1.60	1.58
		sub-grade	19.11	14.44	-	-
LyA	Control	surface	17.78	16.67	1.78	1.71
		sub-grade	20.24	17.60	-	-
Lu ⁴	3:1	surface	16.67	11.41	1.69	1.57
		sub-grade	20.09	10.71	-	-
Lu	6:1	surface	20.66	7.74	1.56	1.64
		sub-grade	28.26	10.94	-	-
Lu	PG	surface	20.86	14.48	1.67	1.67
		sub-grade	24.46	27.00	-	-

¹Bulk density is g/cm³; ²LyA is Lynchburg soil series

³P&G is Pack & Grade; ⁴Lu is Luverne soil series (LuB and LuC)

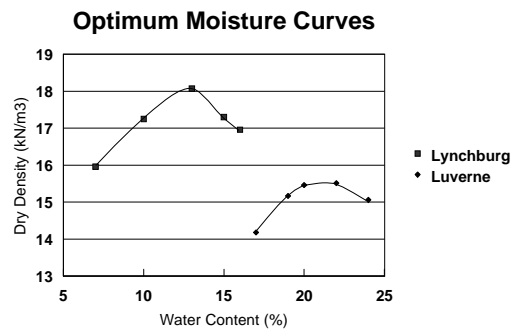


Figure 2. Proctor curves for two soil types.

Construction Costs

Applications costs were estimated for a grader, soil stabilizer, roller compactor and tank truck. Machine rates for the grader, compactor and tank truck were obtained from the February 2000 Cost Estimating Guide (USDA 2000). The rate for the soil stabilizer was based on a monthly rental rate plus costs for fuel and teeth. Labor rates were based on Davis-Bacon wage rates for heavy equipment operators in Lee County, AL plus 30 percent benefits. Delivered cost of the chemical was \$1.00/gal. Applications costs are summarized in Table 6.

Table 6. Machine and chemical costs for application.

Cost Item	
770B Grader w/operator	\$58/PMH
Roller compactor w/operator	\$52/PMH
CAT SS-250 Soil stabilizer w/operator	\$113/PMH
Tanker truck w/operator	\$36/PMH
Unitol DKG @ 3:1, 1.5 gal/yd ²	\$3,080/mi

The total operating cost was \$259/PMH. With a production rate of 1mi/day, assuming 8 SMH/day, the total chemical application cost is \$4893/mi. An increased production rate could be achieved by higher travel speeds or a reduced amount of treated soil. By tilling to a shallower depth a smaller, lower cost soil stabilizer could possibly be used. However, the application cost is more sensitive to chemical quantity than to production rate, since chemical cost is 63 percent of the total application cost. For example, increasing the production rate by 25 percent (1.25 mi/day) decreases the cost by 7 percent (\$4530/mi). However, using a 5:1 dilution rate reduces the cost by 20 percent (\$3866/mi).

CONCLUSIONS

The incorporation of Unitol into the road surface appeared to enhance strength as indicated by the field CBR values. The 3:1 dilution rate exhibited a higher strength for both soil types than the 6:1, pack and grade and control treatments.

Surface strength also increased over time though part of this was due to a settling effect. Laboratory CBR tests showed that under soaked conditions for the sandy loam soil the 3:1 dilution managed to retain its cohesiveness. However, the 5:1 dilution had a slightly higher soaked CBR value than the 3:1 dilution, though the 5:1 weakened with soaking. Laboratory CBR values for the loamy sand soil were highest for the control under unsoaked and soaked conditions but the control had the only decrease in strength (-34%) after soaking.

There was a general drying trend in moisture content of the surface layer for both soil types and all treatments during the 5-month period. The change in moisture content from November to March indicates that the pack and grade and control treatments were wetter in the surface layer than the chemically treated sections for both soil types. This suggests that the chemical could have acted as a barrier and shed the water rather than allowing it to penetrate through the surface.

Moisture content of the sub-grade did not increase during the 5-month period, even for the pack and grade and control treatments. For the Lynchburg soil type sub-grade moisture content was fairly constant in the chemically treated sections. The Luverne soil type displayed a drying trend in the sub-grade for the chemically treated sections.

Post-treatment bulk densities indicated that maximum compaction was achieved on both soil types during the application since these values are near those on the Proctor curves that correspond to maximum density at optimum moisture.

It is important to understand and control moisture content during the application of this chemical. If the soil becomes too wet it will be impossible to achieve maximum density during the compaction process. It would be beneficial to obtain Proctor information for the soils of interest prior to application.

Soil type and their engineering properties are also important factors to consider. The Lynchburg soil, which had a plasticity index of 7, responded better to the chemical than the Luverne soil type, which had a plasticity index of 20. A county soil survey should be obtained prior to application.

Transportation planning will be required for cost-effective use of lignin-emulsion. Roads that will be critical for use in upcoming winter months need to be identified since the greatest benefit is achieved by maintaining access on these critical roads during wet weather.

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